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Content

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Contents

Manned Hot-Air Balloons As Warm Fog Research Vehicles

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Abstract

The utility of tethered and free, manned hot-air balloons for warm fog research is examined. Advantages and limitations of the balloons in comparison to other airborne platforms are considered. The manned hot-air balloons are very suitable platforms for studies that require that heavy payloads be carried with minimum disturbance to the fog.

Tethered, manned hot-air balloons have been successfully used by the Earth and Planetary Sciences Division of the Naval Weapons Center to test droplet charging and hygroscopic spray devices for dispersing fog. An instrumented hot-air balloon is being readied for a study of fog properties that regulate potentials for fog modification.

1. INTRODUCTION

Fog is cloud at ground or sea level. Fog inhibits visual observafion and presents navigation hazards for airborne, sea-going and land-based vehicles. For example, a fog that reduces visibility to less than one-half mile and ceiling to less than 200 feet will close most airports. Warm fog, as compared to supercooled fog, is colloidally relatively stable. Supercooled fog may be quite simply and rapidly dissipated by triggering a phase change by introducing ice. However, a very simple, quick-acting, and practical method for triggering the dissipation of warm fog has yet to be developed. Some 95% of all fog occurrences are warmer than freezing, so research leading to effective warm fog dissipation techniques is vital.

Laboratory and field research of warm fog is being conducted by the Earth and planetary Sciences Division (EPSD) of the Naval Weapons Center (NWC). This research has two basic aspects: (1) Identification and measurement of fog processes and properties that affect potentials for fog modification; (2) development and testing of experimental fog dissipation techniques, including monitoring of the effects on fog and the fog environment.

In the field, either aspect of this research requires platforms for observation and for operation of fag-dispersing and measuring devices. The information needed, or the nature of the dispersal technique, dictates what types of platform should be used. The manned, hot-air balloon is one alternative. Some advantages and limitations in using these balloons in warm fog work are recognized here. Past and planned applications by the EPSD are discussed.

2 PLATFORMS FOR FOG STUDIES

The platforms used-in warm fog research may be mobile or stationary, ground-based or airborne. Ground level platforms are usually stationary; the fog is treated or observed as it drifts past a fixed point or array of points. Towers extend the capability of ground-based platforms to the vertical dimension, up to, say, 100 feet above ground level. The total depth of shallow fogs such as newly developing radiation fogs may thus be studied or treated. Towers reach into only the Lower portions of most fogs, which commonly exceed depths of 500 feet.

Observations of fog made from stationary, ground level platforms and tovers are very useful, although they do not represent the total fog system. Targeting fog dissipating materials and treating sufficient depths of fog from these platforms is difficult, even when expensive arrays are employed.

Airborne carriers can be used to complement ground-based measurements by extending the dimensions of the fog volumes observed. Also, targeting seeding material and treating appropriate fog volumes is most readily accomplished from aloft, when the fog dissipating device is compatible to mounting in or on an airborne carrier.

The various space and time requirements of airborne fog research operations are listed in Table 1. Fixed-wing aircraft, helicopters, kytoons, free constant-level balloons, and hot-air balloons all offer advantages and disadvantages. Operational space and time requirements that could be met with hot-air balloon flights are indicated in the Table.

In the tethered mode, manned hot-air balloons add to the vertical dimecsion of fixed-point tower measurements, and are suitable for certain small-area tests of fog dispersal devices. Since the tethered balloon system is portable, the point of launch may be readily changed between flights. Thus, for example, the testing position may be coordinated with the wind field that prevails at the time of launch. Vertical profile measurements may be acquired with a tethered hot-air balloon by raising and lowering the balloon itself, or by lowering and raising an instrument package from the balloon. Either a movable package or a package susgended at a fixed distance below the balloon avoids contaminating effects on the fog due to heat, water and particulates from the burner that powers the balloon. Ideally, the hot-air balloon is used to locate fog top, and operation is maintained just above fog top. Measurements at a desired position relative to fog top and profiles on ascent and descent through the fog depth and the fog/clear-air boundary can thus be obtained. This type of operation allows visual observation of fog top structure, which is important to characterizing fog life cycles.

Fixed level or profile measurements from a free, manned hot-air balloon can be obtained in much the same manner. The balloon pilot can control the level of any suspended instrument package relative to fog top, and thus eliminate the need for remote-control devices. The advantage of a free balloon is that it will drift with a given fog volume or "parcel". A given section of fog top and a specific flowing volume of foggy air can thus be continuously monitored and/or treated with dispersing materials, with minimum disturbance of the fog by the carrier. Such an operation has not been experimentally tried but might well provide valuable information on the evolution of fog. The balloon operating at fog top with an instrument package suspended into the fog may be expected to track a given fog volume in cases when (1) wind shear is near zero between balloon and package, (2) airflow is consistent, calm, or changing quite slowly so momentum does not cause the balloon to overshoot or lag drift of the fog volume, and (3) vertical mixing in the fog is minimal or accounted for by measurement or calculation.

Most time requirements for airborne fog operations (Table 1) can be met with a manned, hot-air balloon. The main exception occurs when a large foggy .area is to be treated or observed in a short time. The only other real restriction is the limit on flight duration imposed by the fuel supply and the size of the payload. For example, the payload of NWC's balloon can be as heavy as 1,400 lbs, but flight time is limited to 1-3 hours with one fuel tank. However, a tethered balloon can be landed, refueled and launched again with an interruption in measurement of less than an hour, provided the refueling technique allows the balloon to remain inflated. Free hot-air balloons present a greater logistics problem, but free flights exceeding three or four hours would be an uncommon requirement in fog operations.

The hot-air balloons and fixed-wing aircraft serve quite different functions in fog research. On the cther hand, hot-air balloons, kytoons, constant-density-level balloons, and helicopters can serve relatively similar purposes. Table 2 summarizes some advantages and disadvantages of manned hot-air balloons in comparison to these cther vehicles. A principal advantage of the hct-air balloon is the

TABLE 1. Various Space and Tine Requirements of Airborne Fog Operations

SPACE	EXAMPLES OF PURPOSE
Specific Level(s)	
Line paths boxing large or small area	Measure net flux of fog liquid water through volume
*Cross-wind path	Line seeding, to enhance targeting
Path of drift with wind and fog parcel	Monitor changing fog properties (e.g., droplet size) in given volume; continuously treat same fog vclume.
*Fixed point(s) aloft	High point-source testing of fog dispersal devices.
Vertical Profiles	
*Over fired point(s)	Extend vertical dimension of tower measurements.
In cross-wind plane	In-fog sampling of liquid water to measure effect of line seeding
*In plane parallel to wind, moving with air/fog volume	(Same as at specific level, vertical dimension added)
TIME	
Increments	
*Continuous	Monitor evolution of fog properties, especially during seeding.
*Fixed intervals	
seconds	(same as with continuous monitoring)
minutes	Repeat line-path seeding to increase dosage
hours	Monitor gross changes in fog (extent, depth, density)
Duration	
*Seconds	Accomplish line-path seeding
*Minutes	Induce and monitor changes in fog properties
*Hours	Monitor fog life cycles

*Feasible with manned hot-air balloon.

TABLE Characteristics of Certa borne

	Vehicle Control	Payload	Operating Altitudes (above ground level)	On-station time
Manned hot-air balloon				
Tethered	Direct; altitudes only, as modified by tether; wind gusts, speeds greater than 7-8 kts, reduce control; operation above and in fog OK	Up to 1,400 lbs (example)	Up to approx 2,000 ft	1-3 hr with each fueling; 2nd tank means more time, less payload. Fixed position
Free	Direct, altitude only; risky within fog, but transponder aids navigation.	Same, but sacrifice some weight for maneuverability.	Unlimited	4-6 hr maximum; sufficient; follows airflow/fog volume.
Helium-filled kytoon	Tether; variable winds, etc., restrict constant altitude control; operate in or above fog.	Up to approx 120 lbs (standard models)	Limited by weight of tether	Order of 24 hr; limited only by diffusive helium losses; fixed position.
Constant-density-level balloon	None required, free, tracked by radar; operates in or above fog.	None or 1-2 lb package (serves to track airflow/fog parcel, may carry small telemetered sensors)	Unlimited	Many hours; normally very sufficient to to follow air parcel across fog dimensions
Helicopter	Direct (horizontal, vertical); good above fog, very poor in fog.	Maximum	Unlimited	Approx 2 hr, then relieve pilot; fixed position, or large or small area coverage.

TABLE 2. Characteristics of Certain Airborne Carriers—continued

	Night Flights	Disturbance to fog	Direct Visual Observations from operating level	Operating Expense
Manned hot-air balloon				
Tethered	OK if IFR equipped with rate of climb/descent indicator	Heat, H_2O, particles and gases from rising burner exhaust (Position sensors accordingly).	Yes	Moderate
Free	Not recommended	Same	Yes	Moderate
Helium-filled kytoon	Same as in daylight	Minimal	No	Minimal
Constant-density-level balloon	Same as in daylight	Minimal	No	Minimal
Helicopter	OK above fog	Downwash and exhaust constituents cause considerable fog modification over significant area, depth.	Yes	Substantial

heavy-payload capability. Direct visual observation from the operating level is also helpful. The crew of 5–7 men required for launching, controlling and piloting a hot-air balloon accounts for most of the moderate operating expense. A tethered hot-air balloon cannot be safely operated in winds exceeding about 8 knots. This restriction limits operations in advection fogs, in particular, but should not hinder studies of radiation fogs.

A helium-filled kytoon may be flown on station for a very long time, with a minimal crew. However, several kytoons operated individually or in tandem may be required to carry a complete payload. Hot-air balloons are generally more stable than kytoons.

Constant-level balloons are excellent for simply tracking airflow through fog, provided ground clutter does not interfere with the radar's function. This application would be useful for determining the lifetime of fog droplets, for example. This type of balloon could carry some miniaturized sensors, but it is not designed to carry a significant payload.

Helicopters are useful for fog dispersal tests in which the effects of the downwash are desired to act in combination with other dispersal agents such as hygroscopics. The disturbance to the fog greatly limits the utility of helicopters in fog characterization studies. The fog disturbance by hot-air balloons is relatively insignificant.

3. A BALLOON-BORNE DROPLET CHARGING SYSTEM

Warm fogs can be dispersed if the fog droplets can be induced to collide and coalesce, so as to gain sufficient mass to settle out. Electrically charged droplets are much more efficient collectors of other droplets than are uncharged droplets. Carroz, et al (1972) estimate significant increases in visibility in fogs that are sprayed with charged droplets of water or hygroscopic solutions. These potentials prompted development and testing of a droplet spraying and charging system by NWC with cooperation from the U.S. Army's Atmospheric Sciences Laboratory and the Federal Aviation Administration. During Project Foggy Cloud IV, charged water drops were sprayed from a hot-air balloon into small volumes of fog and open air, thus permitting laboratory type experiments to be conducted in the field. Details of the project and the results are reported by Loveland, et al (1972). Highlights are presented here to show how the balloon was used.

Field tests were conducted utilizing an induction charging system and pressurized water delivery system. This apparatus was lifted by a tethered manned hot-air balloon 60 feet in diameter with a payload capacity of about 1,400 pounds. Propane burners propel this balloon.

The charged drop-producing system in its field-ready form (Figure 1) used 48 Delavan 30-degree hollow-cone nozzles. Each nozzle Is designed to give a median drop diameter of 100 um and a spray race of 8.8 gal/hr at 125 psi. Conical induction rings were utilized. The 30-degree angle of the rings coincided with the 3C-degree nozzle spray pattern (Figure 2). The entrance openings were rounded to discourage arcing between nozzle and induction ring. All nozzles combined to produce a spray rate of approximately 6 gal/min. Negatively-charged spray was produced with the emf source attached as in Figure 2; positive spray was provided by reversing the source. The assembly plumbing which supported the nozzles, was an octagon (Figure 1) with sides about 12-feet long, supported by cables, and was 20 feet below the gondola. Twenty-four cables were used, as the plumbing itself was not rigid. A water tank pressurized by compressed citrogen or helium fed the assembly. In early experiments, a ground-mounted emf source was used; however, a portable emf source (thirty 90-volt radio-type B batteries) was constructed for higher altitude testing. This source provided about 2,700 volts when fresh .and deciined to 2,200 volts after use.

Field tests were conducted at the Xrcata-Eureka Airport and in Redwood Valley, both in the north coastal region of California. Clear air tests demonstrated that the balloon system could produce charged droplets, and that these droplets would hold their charges for times sufficient to produce interaction with fog droplets. The induction rings tended to collect the highly nobile, oppositely charged fine droplets (< 20 um diameter), thus eliminating possible fog enhancement by these particles. Effects of charging the spray could be seen visually. Under calm wind conditions, uncharged droplets settled downward from the spray boom as expected under the influence of gravity (Figure 2a). As droplets with one polarity were sprayed, they were attracted to the balloon system, which was grounded by the tether. Small and mobile charged droplets were drawn back and upward toward the balloon under the Influence of the field produced between the balloon and the space charge of the spray.

An interesting question is that concerning the effect of **the** earth's natural field on charged droplets. Generally, the earth's natural field goes to positive with altitude, and may be of the order of 100 to 1,000 V/m in fog. Positive drops could be forced down faster than gravity alone would drive them; negative drops could be given an increased tendency to remain up. The experiments demonstrated, however, that the spray-generated local fields overshadow the earth's natural fields, except when drops drift enough horizontally to be out of the generated high locai field. In field measurements using a field mill, fields of 4,000 V/m were consistently generated under the spray of charged drops. A field of this magnitude can substantially affect droplets with 16 µm diameters or less, as was visually observed. However, the predominance of spray droplets were considerably larger and relatively unaffected by either the induced or natural fields.

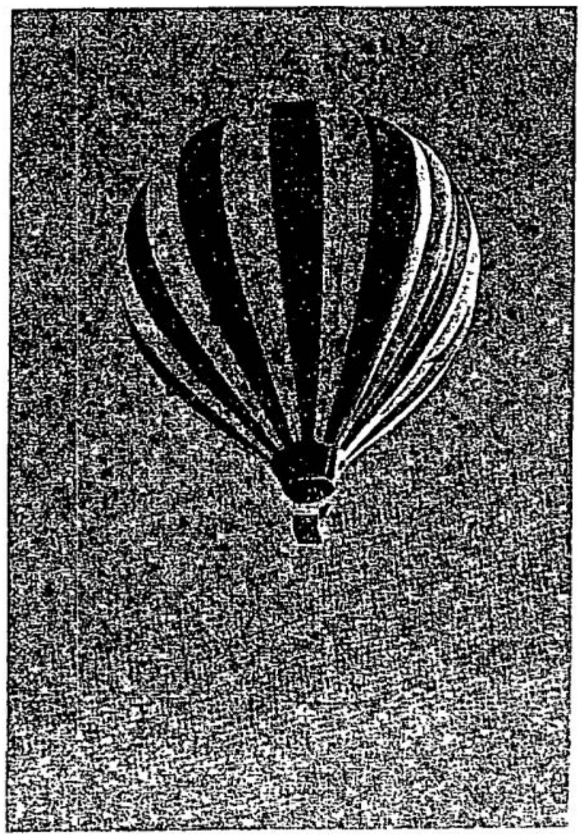


Figure 1 Spray Assembly Suspended From Balloon

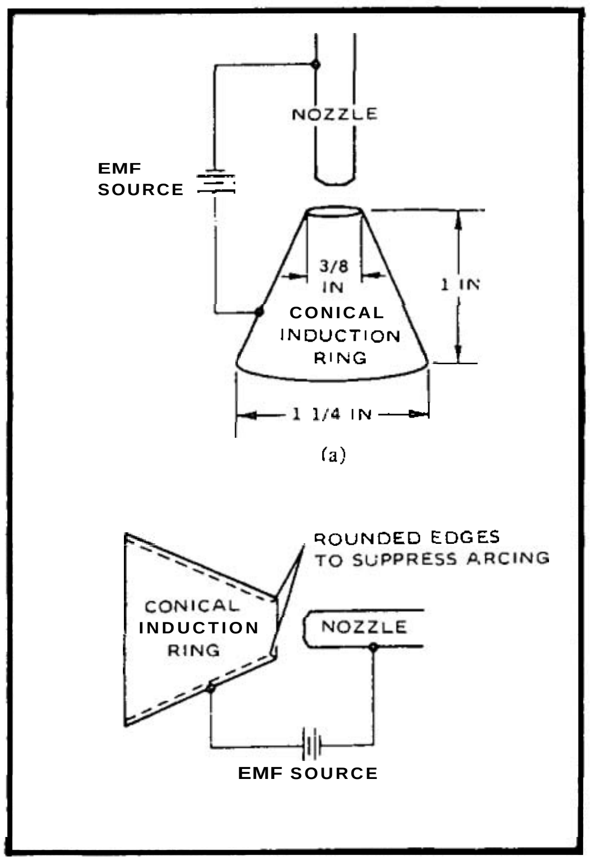
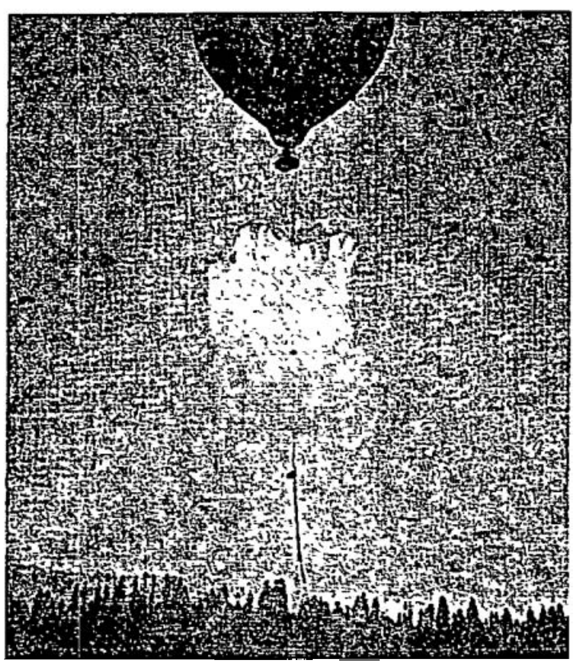
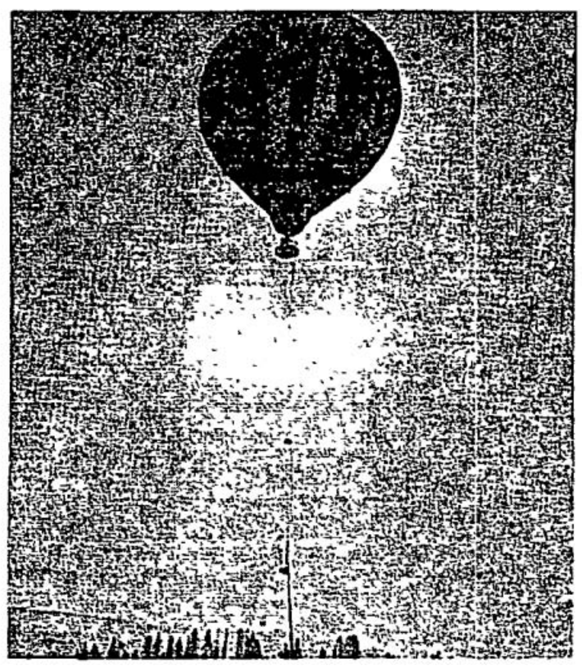


Figure 2 Conical Induction Ring (a) Simplified view showing significant geometry, (b) mechanical details



(a) Uncharged spray



(b) Charged spray, showing drops rising and intercepting balloon

Figure 3

The small, charge-carrying droplets that return to the spray rig constitute a feedback current. Unless such dropiets gain mass by collecting fog droplets during their transit, so as to avoid total return, they can reduce the effectiveness of this type of system. Therefore, procedures to reduce this feedback were tested. A feedback reduction is observed as an increase in current between the spray system and ground. An experiment was carried out to deternine whether use cf a blower would increase ground current by preventing the free charges, or charged droplets, from returning to the grounded spray assembly. First, a single nozzle system with the balloon-inflator blower was tested near ground level, as illustrated in Figures 4 and 5. Minus 2,250 volts were applied to the induction ring to produce a positive spray. With the blower off, measured ground current was 2 microamperes; with the blower on, measured ground current was 4.5 microamperes. The blower did reduce feedback.

To determine the effectiveness of the blower at higher altitudes, a specialiy constructed nine-nozzle system with the blower was constructed. The ground current was found to decrease with altitude between ground and 100 feet, but not as rapidly as without the blower; the feedback reduction was altitude-dependent. The pattern was apparently due to stronger droplet attraction by the earth at lower altitudes.

Fog was unfortunately not encountered during the scheduled test period, but the tests of the balloon-borne charging system did show that this fog dispersal method was worthy of further research. This research is in progress. The hot-air balloon was an excellent vehicle for the tests conducted.

4 HYGROSCOPICS SPRAYED FROM THE BALLOON

Hygroscopic particles rapidly grow by vapor diffusion in saturated, foggy air. The resulting solution droplets may be large enough to collide and coalesce with fog droplets. These effects can lead to fog dissipation as the large droplets settle out.

The FAA requested of NWC that liquid hygrosocopic chemicals such as glycerine, diethylene- and tetraethlyene-glycol, proposed and furnished by Dow Chemical Company, be tested using the hot-air balloon. The balloon system for these tests is depicted in Figure 6. The balloon carried 30 gallons of the test chemical in the gondola. The chemical was sprayed from the gondola using the Dow spinning disc particulator (see McDuff, et al, 1971). A cable carried power from the ground to the balloon and supported a vertical array of droplet samplers. These samplers were used to determine if the droplets of chemical changed in size by collecting either water vapor or the visibility-restricting droplets.

Clear-air tests were conducted with all three chemicals. The objectives of the clear-air tests were to measure the drop size-distribution from the particulators, and to observe the characteristics of the plume. In brief, drop size-distribution

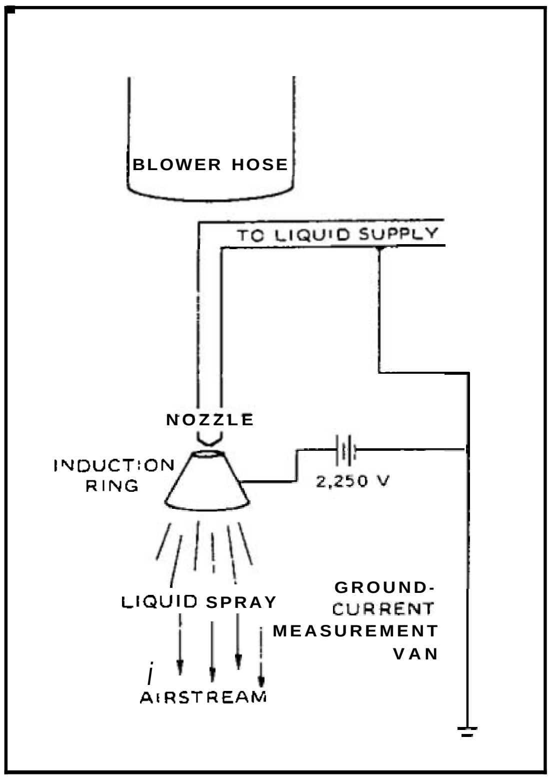


Figure 4 Single-Nozzle System With Blower

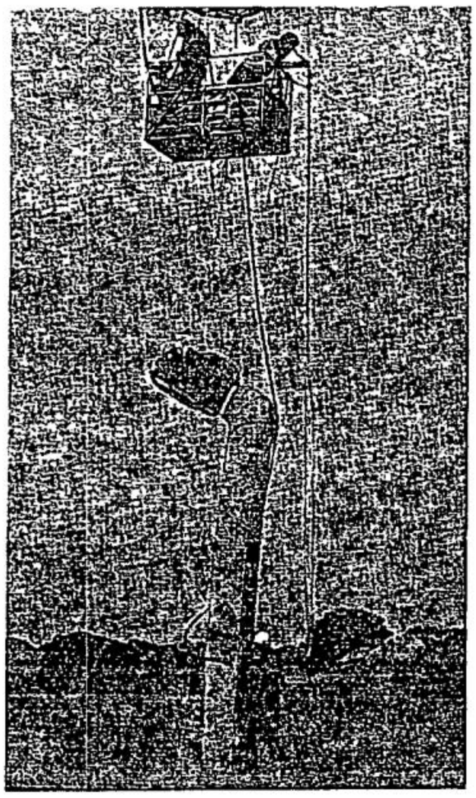


Figure 5 Single-Nozzle System With Blower. Ground Test Layout

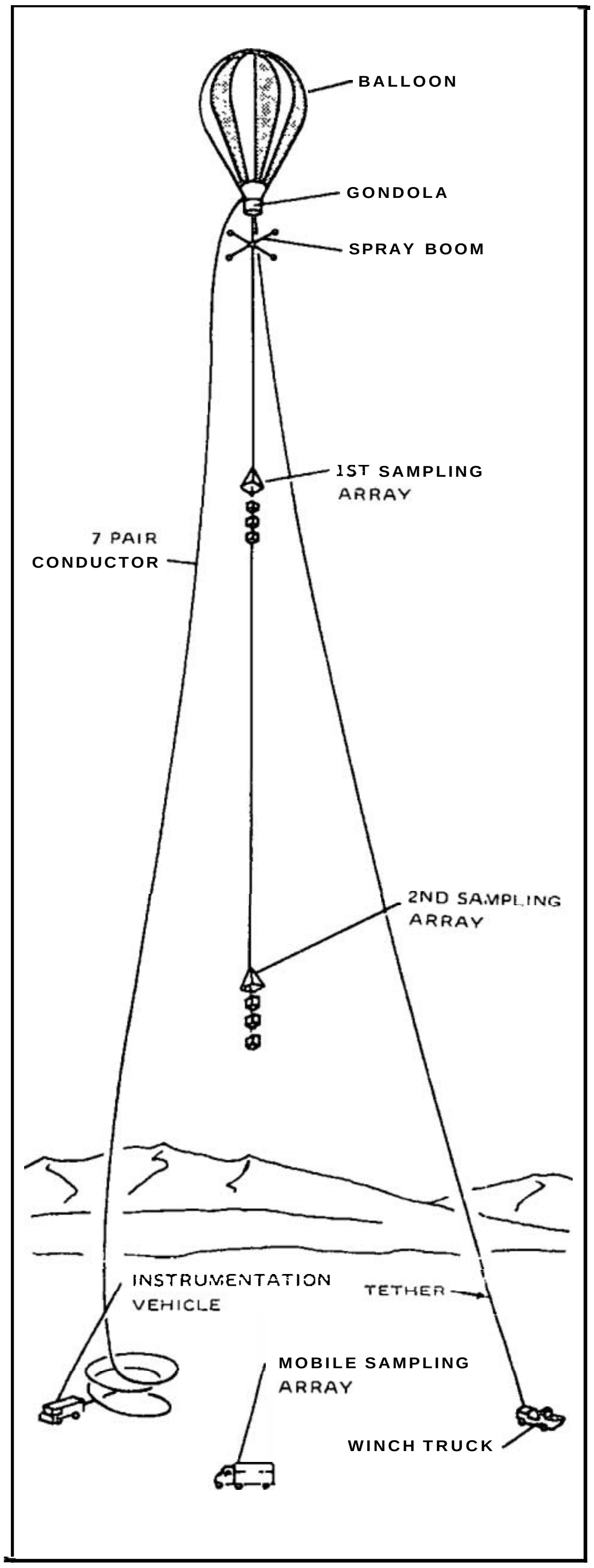


Figure 6 Hot-Air Balloon System for Hygroscopic Spray Tests

Figure 7a Four Minutes After Spraying Began

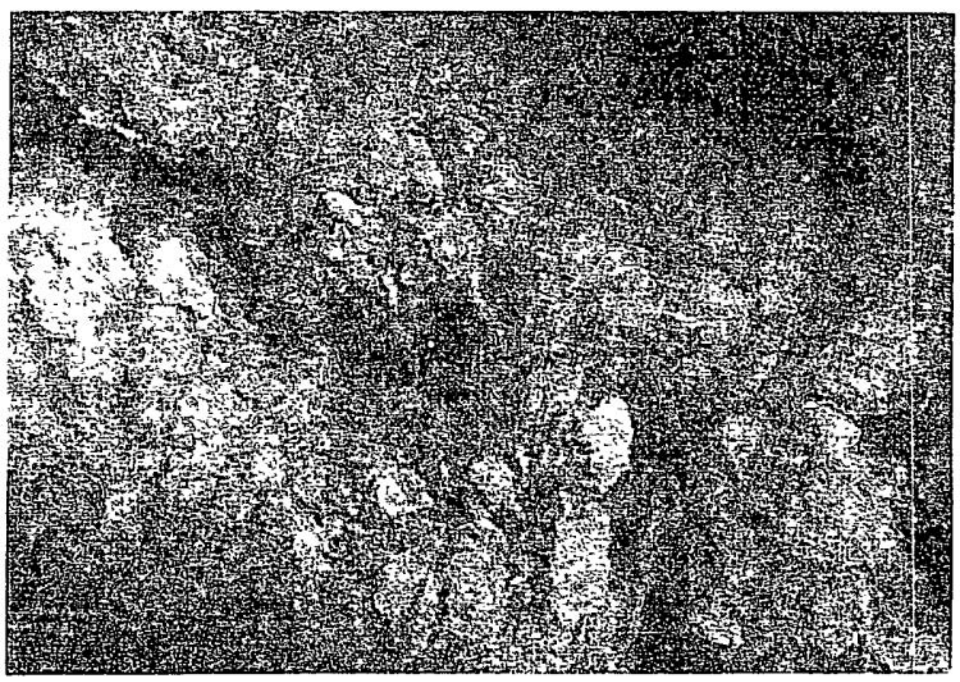


Figure 7b Seven Minutes After Spraying Began

Figure 7 Photograph? of the Fog-Abatement Test From tha Navy U-3 Aircraft Flying at 10,000 ft The balloon is in the center of each picture samples obtained from the disc particulator showed that over 78% of all drops had diameters less than 30 μm, regardless of the collection distance below the balloon (Hindman and Clark, 1972). Evaporation of the chemical drops should not have caused a significant effect in the humid coastal environment. These droplets were somewhat smaller than desired for optimum effects on fog. The maximum flow rate from the disc particulator was 2.7 gal/min.

McDuff, et al (1971) report that the plume was approximately 10 feet in diameter immediately below the particulator which was at 100 feet AGL. In calm wind conditions the plume was observed to diffuse to approximately 20–25 feet in diameter. As the wind velocity increased to 2 to 3 knots the width of the plume increased to approximately 220 feet at the ground.

Because of the clear weather, only one cloud dispersal test was conducted. A stratus deck with base near 250 feet AGL, and top near 500 feet AGL, filled Redwood Valley. The balloon was loaded with glycerine preheated to 30°C to decrease viscosity and enhance the flow rate. Only 14.5 min after launch, the balloon was stabilized at 450 feet AGL and began spraying. Heat from the balloon was the most probable cause of the large depression around the balloon observed some 3 min after stabilization (Figure 7a). The balloon releases roughly $3 \cdot 10^6$ btu/hr in tethered flight, according to J. Craig, the pilot (personal communication). Each cubic meter of cloud that drifted by the balloon was calculated to receive about 453 calories, enough to cause local evaporation.

A small rift was cut through the fog depth well before the end of the 9.3 min spray period (Figure 7b). Droplets of glycerine water solution were observed at the ground under the hole. The amounts of glycerine sprayed amounted to 21 gal/acre, which was calculated to be more than sufficient to cause the hole by the processes of vapor diffusion plus droplet collision–coalescence (Hindman and Clark, 1972). Other studies by NWC indicate that certain liquid hygroscopics, and an ammonium nitrate–urea–water solution in particular, are reasonably effective in dissipating fog. More efficient means are still being sought.

5. FUTURE FOG STUDIES WITH HOT-AIR BALLOONS

The EPSD is currently funded to conduct a basic fog characterization study with the manned hot–air balloon. Emphasis will be placed on studying the boundary layer between dense fog and clear air above the fog. Acquisition of profiles of certain parameters through the fog will also be attempted. The study will be conducted primarily in the warm, winter radiation fogs that form in the San Joaquin Valley of California. The formative and ripening stages of these fogs are of particular interest, since processes at these stages may hold potentials for modification to prevent or dissipate fog.

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